1.2 Site Description

The St. Louis adit and associated settling ponds are located on the eastern edge of Dolores County approximately 1/2 mile north of the town of Rico, Colorado, as illustrated in Figure 1.1. The entire site skirts the eastern bank of the Dolores river and occupies about 80 acres. Rico, at an altitude of 8800 feet, is surrounded by the 12,000 foot peaks of the Rico Mountains in the San Juan National Forest. Twenty five miles to the northeast is the town of Telluride, and 44 miles to the southwest is the town of Cortez.

The water emanating from the St. Louis adit originates in mine workings aggregating several miles. This discharge is treated with quick-lime (CaO) and is regulated by CPDES permit No. CO-0029793, through the Colorado Department of Health. It is understood that the flow from the adit represents generalized groundwater seepage and storm water run-off. According to weather observations received from the National Weather Service from 1961 to 1995, the mean annual precipitation and snowfall measured at the Rico Climatological Station (Station NO. 05-7017-2), are 29.46 and 181.92 inches, respectively.

The ponds are contained within man-made dikes constructed in unconsolidated material underlain by an alluvial aquifer and a major geothermal fault. This geothermal fault zone appears to be the source of artesian flows which naturally flow into the river via numerous hot springs located along the rivers banks (Weir et al. 1983; Pratt et al. 1969; Cross et al. 1905). This phenomena is evidenced by the occurrence of bubbles of carbon dioxide and geothermal wells throughout the lower series of treatment ponds. According to reports from the Colorado Department of Health, the ponds were constructed with native material without liners or run-on/run-off controls (Schrack 1995).

The configuration of the site in 1980 consisted of 19 settling ponds, a heap leach pad and sulfuric acid plant north of the ponds, and maintenance buildings north and east of the ponds (Figure 1.2).

However, to date, the acid plant and maintenance buildings have been demolished, and the heap leach pad has been remediated. Only 10 of the 19 ponds are currently being used for water treatment. Ponds 16, 17, and 19 have been completely back-filled. Pond 13 is completely drained of water, but not back-filled. There is a strong suggestion of calcine tailings from the old acid production plant evidenced by dark, brick-red sediment. Pond 10 is full of water, however there is no visible connection to the rest of the system. Ponds 1 through 4 have been allowed to become a natural wetland and exhibit an abundance of plant and wildlife. The previous heap leach pad site is now a new pond, with a volume of approximately 625,000 cubic feet. It is currently being used as a holding area for dredged material (Figure 1.3). CPDES Outfall 002 currently exits to the Dolores River at Pond 5. In addition, a lime treatment plant has been installed at the St. Louis adit, and has been treating the mine drainage since 1984. Figure 1.4 shows the location of the treatment plant in relation to the adit and the first settling pond (pond 18).

Figure 1.3. New holding pond estimated to be approximately 625,000 cubic feet. The St. Louis adit drainage is located to the east, just outside the right hand side of the photo.

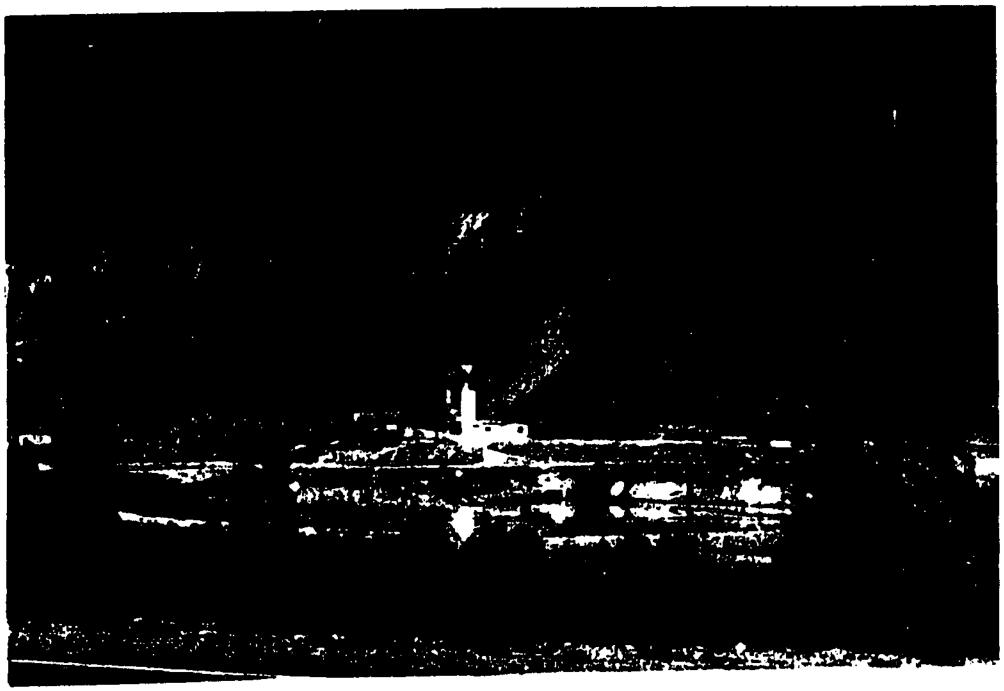

Figure 1.4. Location of the water treatment plant in relation to the adit and the first settling pond. The adit is located directly behind the plant, and the pond in the foreground is pond 18.

1.3 Organization

The purpose of this thesis is to identify existing or developing technologies that could have an impact on the remediation of the St. Louis adit drainage and associated settling ponds. To meet this objective, it is necessary to have an understanding of the nature of mine drainage and available remediation technologies. Most importantly, the specific characteristic of a site and any regulatory constraints must be determined before practical recommendations can be made.

The organization of this thesis provides the reader with a comprehensive guide to the problem and resulting recommendations for the remediation of this site. The introduction outlines the motivation for this research and presents the location and description of the area. Chapter 2, the literature survey, provides the background necessary to understand the nature of the problem and the proposed solutions. It includes the history of the site, a description of the chemistry of mine drainage, and the technical aspects of pertinent remediation technologies. Chapter 3 describes the experimental methods and equipment used to characterize the site. Chapter 4 provides a detailed discussion of the results and the treatment options proposed. Chapters 5 and 6 outline the conclusions of this research and the resulting recommendations, with suggestions for future work.

Chapter 2

LITERATURE SURVEY

2.1 Introduction

Mine drainage is a critical problem throughout the United States. Thousands of miles of creeks and rivers are effected, many located in Colorado. Polluted sites, a reminder of Colorado's mining past, dot the map from the Denver area to the Western slope. The environmental impact of these mines range from unfavorable esthetics to metals and sediment transport and acidic drainage. Hence, it is essential to know how mine drainage conditions are generated, and how they can be mitigated.

The process of mine drainage treatment begins with an understanding of the source and effect of water pollutants. A characterization is then developed and interpreted to forecast treatment needs. In addition, site specific characteristics and the features of existing and proposed treatment systems must be considered. This knowledge will help provide insights into the appropriate remediation techniques which could be applied at a specific site. This chapter is intended to provide background information on the Rico site, an introduction to the origin of mine drainage, and a general understanding of the possible treatment options available.

2.2 Site History

The Rico-Argentine mining site began operations over 100 years ago as a silver producer. The major goals of the now inactive mining operations consisted of precious metal mining, base metal production (lead, zinc, and copper) from sulfide ores, and sulfuric acid production from pyrite ores. The St. Louis adit drainage and associated settling ponds on the Dolores River are considered an extension of this mining area, and are the focus of this study.

A series of ponds have been used for the last 12 years to assist in the remediation of mine drainage from the St. Louis adit. However, historical data provided by ARCO indicates that the ponds have been in existence since the 1950's and have been used for other purposes as well. The following is a chronological summary of significant background information pertaining to previous operational and remedial activities in the Rico-Argentine mining area, prepared for ARCO by ESA Consultants Inc. of Fort Collins, Colorado (ESA 1995).

1869 The first mining claim was established along the Dolores River in Rico.

1872 The first crude smelter was built. It produced three bars of bullion before collapsing.

1880 The Grand View Mining & Smelting Company built a small smelting operation on the east bank of the Dolores River near the bridge just North of the town of Rico. This was motivated by high freight cost to ship the ore to Durango ($300/ton).

1883 A temporary peak in silver production occurred producing 193,360 ounces of silver.

1884 A second smelter was built at the southern end of town, and operated for two years.

1887 The famous Enterprise gold-silver blanket ore body was discovered in the Enterprise Mine shaft. This shaft was located in the Newman Hill area southeast of the town.

1893 An all-time peak in production in silver and gold occurred. 2,675,000 ounces of silver, and 442,000 ounces of gold were recovered. At this time, the population of Rico grew to 12,000 and 20 active mines producing gold, silver, lead, zinc, and copper were in operation. However, in mid 1893 a silver panic gripped the area and a decline in silver production was experienced.

1902 Intermittent mining activity began and lasted until 1925. The principal production was base-metal ores such as lead and zinc. The ore was shipped to custom flotation mills in the Salt Lake City area. During this time, the Rico-Argentine mining company incorporated, and a temporary peak for base metals was experienced, producing 1,540 tons lead, 1,300 tons zinc, and 916 tons copper. Most of the copper was mined primarily from the Mountain Spring-Wellington mine of the Rico-Wellington Mining Company in CHC Hill.

1925 The St. Louis Smelting & Refining Company, a division of the National Lead Company and after May 1927 the successor of the Rico Mining and Reduction Company, mined the CHC Hill, the Silver Swan Mine, and along the Silver Creek (Figure 1.1). Other chief producing companies during this time included the Rico-Argentine Mining Company, Union Carbonate Mines, Inc., and the International Smelting Company (a subsidiary of Anaconda).

1926 The International Smelting Company operated the Falcon Mill located at the North end of town between highway 145 and the Dolores River until 1928. After the mill shut down, the ore was once again shipped to custom mills in the Salt Lake City area.

1927 An all-time peak in base metals was experienced. 4,994 tons of lead, 5,308 tons of zinc, and 65 tons of copper were mined.

1929 Rico, along with the rest of America, was hit by the Great Depression. By 1932, all production ceased. However, mining resumed on a small scale in 1934. During this time, the St. Louis Smelting and Refining Company drove the St. Louis Tunnel and crosscut extensions into the east bank of the Dolores River under CHC Hill. This caused the tunnel to become a continuous source of mine water discharge into the Dolores River.

1939 The Rico-Argentine Mining Company began operation of the lead-zinc-copper Argentine Mine along with the Argentine Mill. The mill was a 150 ton per day flotation mill located on the Silver Creek.

1941 The Falcon Mill which ceased operations in 1928 was dismantled.

1955 A crosscut from the Argentine Mine on the Silver Creek to the St. Louis Tunnel on the Dolores river was complete. This caused the water level in the Silver Creek area workings to drop 450 feet, reducing the impact of drainage at this site but increasing the flow rate from the St. Louis adit. In addition, the Rico-Argentine Mining Company began operation of the Dolores River acid plant. The plant was located at the St. Louis Tunnel, and processed 165 tons per day of iron pyrite ore producing 0.3 million tons of sulfuric acid to supply uranium mills. This operation generated calcine (iron oxide) tailings which were deposited in what is now considered ponds 11 through 18, see Figure 2.1 (Stephens 1978).

1964 The acid plant was closed by the state for polluting the Dolores River. Fumes from the plant destroyed the vegetation along the valley and adjacent hillsides.

1971 The Rico-Argentine Mining Company mining operations ceased, and the lower 500 feet of tunnels were allowed to flood discharging to the Dolores River at the St. Louis adit.

1973 The Rico-Argentine Mining Company began operation of a 100,000 ton heap leach pad adjacent to the acid plant to extract gold and silver from dump material from the Newman Hill area.

1975 A cyanide heap leach berm failure occurred resulting in an extensive fish kill in the Dolores River. This caused an immediate closure of the site.

1976 The first Colorado Pollution Discharge Elimination System (CPDES) permit, No. CO-0029793, was issued to the Rico-Argentine Mining Company for the St. Louis adit discharge into the Dolores River.

1977 The Rico-Argentine Mining Company merged with the Crystal Oil Company.

1978 The Crystal Oil Company hired Hazen Research, Inc. to sample the calcine tailings in the ponds. The result of their research indicated the ponds contained 234,230 tons of tailings that were suitable for use as an iron additive in the cement industry.

1980 The Anaconda Copper Company acquired the Rico-Argentine Mining Company from the Crystal Oil Company, and the discharge permit was transfered to Anaconda. Anaconda began conducting a deep exploration drilling program for molybdenum ore bodies and performed numerous reclamation and stabilization procedures of the site until 1983.

1983 The State of Colorado filed a Natural Resources Damage claim pursuant to CERCLA (the Comprehensive Environmental Response, Compensation, and Liability Act). However, the EPA denied the claim and the discharge permit was renewed.

1984 Anaconda began operation of a lime addition plant with a series of settling ponds to treat the drainage from the St. Louis adit.

1986 Anaconda, noting poor treatment efficiencies obtained by the old treatment system, added a new lime-slaking facility. In addition, Anaconda removed hazardous substances from the Rico facility and demolished the acid plant and associated structures. The site was then regraded, capped with a soil cover, and revegitated.

1988 ARCO, who briefly owned this site, sold the real estate, mining and commercial properties to Rico Development Inc.

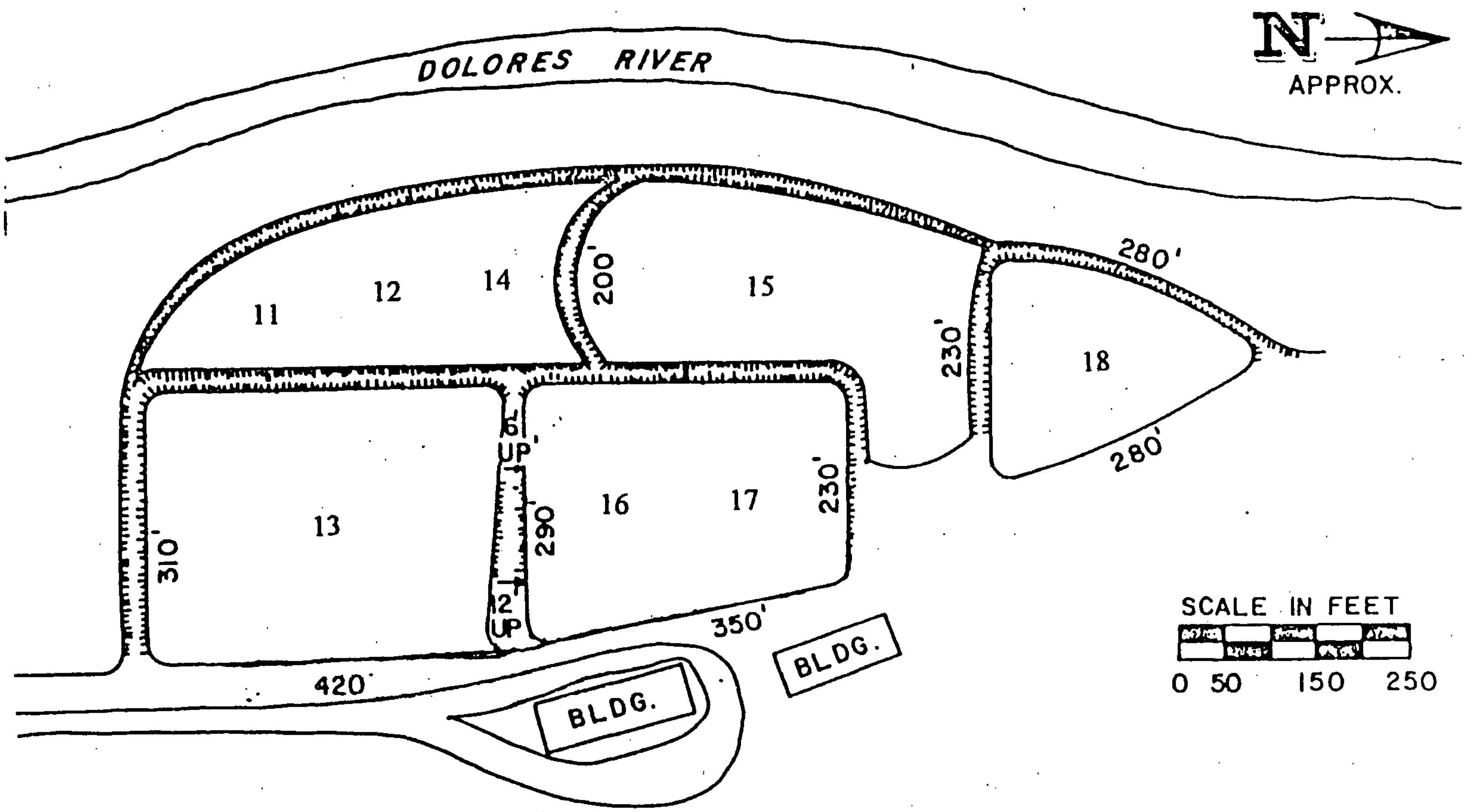

Figure 2.1. Sketch of the Rico-Argentine tailings ponds as they were configured from 1955 to 1978. The ponds were used during this time to hold calcine tailings from the Dolores River acid plant.
Source: Stephens 1978.

Since Rico Development Inc. acquired the holdings, the heap leach pad site was remediated and replaced with a stabilization basin of approximately 625,000 cubic feet, and is currently being used to hold dredged tailings from the upper most ponds. In addition, the water treatment plant continues to operate adding, on average, 600 lbs/day of quicklime (CaO).

2.2.1 Current Water Treatment Plant

Rico Development, Inc. currently operates and maintains a mine water treatment facility for the removal of heavy metals from the mine discharge prior to its permitted discharge into the Dolores River. This heavy metals removal process incorporates neutralization and settling technology, and consists of raising the pH of the water by the addition of quicklime and settling the resulting flocculant in a series of ponds. Studies conducted by the Colorado School of Mines Research Institute (CSMRI) in 1982, indicated that zinc and copper concentrations in the St. Louis adit waters could be removed from solution with lime precipitation at a pH above 8.7 to concentrations below permit limitations. In addition, laboratory work found that adding approximately 30 mg/L of hydrated lime ($Ca(OH)_2$) would raise the pH of the drainage to the necessary value (CSMRI 1982). This estimate was based on an average annual flow rate of 2000 gallons per minute (gpm) and translates to approximately 600 lbs/day of quicklime (CaO). Since the adit flow rate displays seasonal variations, the treatment process was designed to accommodate varied liming rates.

The lime slaking plant[2] consists of a water pumping system, lime storage, slaking reactor, slurry storage, and a discharge system. All the components of this system are

[2] The slaking plant was manufactured by Smith & Loveless, Inc., located in Lenexa, Kansas.

contained within a pre-manufactured Chem-Tower building supplied by Smith & Loveless (Smith & Loveless 1986). Figure 2.2 is an illustration of the treatment plant provided by the manufacturer.

Water to the treatment plant flows from the mine through a cement channel emanating from the St. Louis adit. The water flows to a concrete access box located northeast of the building. This box contains an intake line which feeds the slaker via a pump. Only a small amount of the total flow from the mine passes through the water treatment plant. The remaining water is diverted through an underground PVC pipe to a ditch which flows into pond 18. The water that is pumped to the treatment plant is fed directly to a reactor where it is mixed with quicklime to produce a calcium hydroxide slurry.

The quicklime is stored in the upper part of the tower, which has a capacity of 1,240 cubic feet (250,000 lbs CaO). Based on an average liming rate of 600 lbs/day, this equates to a roughly estimated 12 month supply of lime. The dry lime is fed through a bin activator, a collar which shakes the bottom of the bin to ensure the lime will flow freely. Lime next enters the volumetric screw feeder, where a controller allows for adjustment of the screw speed and thus the rate of lime feeding. A totalizer shows the actual hours of operation of the feeder. Thus, the total lime used in a 24 hour period may be determined. The lime then drops through a slide gate into the reactor. The lime feed system starts and stops automatically by level controls associated with the lime slurry holding tank. Upon demand, the slide gate begins to open. When the gate is fully open, the reactor, feeder, and bin activator are on.

The reactor is a baffled container with a turbine agitator at the bottom for stirring. The maximum lime feed rate to the reactor is 500 lbs/hr and provides a mixture retention time of 10 minutes. Water and lime are vigorously mixed in the reactor, producing an exothermic reaction which converts pebble quicklime to calcium hydroxide. Vigorous mixing enhances the reaction process by stripping hydrated lime particles from the surface of the pebble quicklime. The lime slurry exits the reactor chamber by flowing under a baffle and over a weir into the classifier chamber.

The classifier is a wedged-shaped box with an inclined screw, which when rotating serves to separate the grit from the slurry. A high impact weir jet is directed onto the slurry as it overflows the weir to break it up into a finely divided milk of lime solution. The heavier grit particles settle to the bottom where the screw lifts the grit to a discharge opening located at the upper end of a grit conveyor trough. At the base of the classifier, dilution water is added via turbulence jets. This serves to maintain the calcium hydroxide particles in suspension for carry over into the slurry storage chamber, cleanse the grit of calcium hydroxide particles, and minimize the opportunity for the slurry to plug the plumbing. Slurry spills from the classifier into a slurry storage tank on the ground floor of the plant, where electrodes are used to indicate the level in the tank. The slurry is agitated by a turbine mixer to keep the lime particles and any remaining grit in suspension.

Lime discharge is controlled by a motorized ball valve located at the bottom of the slurry tank. This valve is the key to the control of lime usage. The valve is controlled by timers that can be set to open at any time of day for a specified number of seconds. Thus, the lime is discharged into the remaining water evenly throughout the day with minimal supervision.

The limed water enters a series of 10 ponds designed to provide a residence time of approximately nine days. During this time, the effect of gravity on the particles suspended in the water induces sedimentation. Solids are removed throughout the system, until the water reaches a discharge flume at pond 5. Here, the water flows through a calibrated flume and then into the Dolores River. The object of the entire system is to discharge water that meets the CPDES permit limitations.

2.2.2 CPDES Permit Information

A Colorado Pollution Discharge Elimination System (CPDES) permit was first issued on June 1, 1976 to the Rico Argentine Mining Company for discharge of the St. Louis adit draiange to the Dolores River. The purpose of the permit was to regulate the discharge of toxic pollutants in quantities that might adversely affect the environment. The pollutants in the St. Louis discharge regulated under Permit No. CO-0029793 included cadmium, copper, lead, silver, and zinc. In addition, pH, total suspended and dissolved solids, and the flow rates were limited. Table 2.1 shows the permit requirements.

Since the first issuance, the permit has been transferred to each company who owned the site and is currently held by the Rico Development Company. The current permit was renewed December 30, 1993 for the period of January 1, 1994 through January 31, 1999. Effective February 1, 1995, the 30-day average concentration limits for cadmium, copper, silver and, zinc have been lowered, and the daily maximum concentrations for cadmium, copper, lead, silver, and zinc need only be reported. It should be noted that metals concentrations are total recoverable concentrations. This is the concentration of metals in an unfiltered sample following treatment with a hot dilute mineral acid (EPA Method 3005).

Table 2.1: CPDES Permit No. CO-0029793 Limitations. Permit period is January 1, 1994 through January 31, 1999.

PARAMETER	LIMITATION	PARAMETER	LIMITATION
Flow, MGD (Avg[a])	2.6	Lead, mg/L (Avg[a])	0.0099
Flow, MGD (Max[b])	report	Lead, mg/L (Max[b])	report
TSS, mg/L (Avg[a])	20	Silver, mg/L (Avg[a])	
TSS, mg/L (Max[b])	30	through 1/31/95	
Oil & Grease, mg/L (Max[b])	10	Jan - Apr	0.0002
pH, s.u.	6.5-9.0	May - July	0.0006
TDS, mg/L (Quarterly)	report	Aug - Dec	0.0004
Cadmium, mg/L (Avg[a])		beginning 2/1/95	0.0001
through 1/31/95		Silver, mg/L (Max[b])	
Jan - Apr	0.0024	through 1/31/95	
May - July	0.0055	Jan - Apr	0.0004
Aug - Dec	0.0035	May - July	0.0012
beginning 2/1/95	0.0004	Aug - Dec	0.0008
Cadmium, mg/L (Max[b])		beginning 2/1/95	report
through 1/31/95		Zinc, mg/L (Avg[a])	
Jan - Apr	0.0048	through 1/31/95	0.44
May - July	0.011	beginning 2/1/95	0.237
Aug - Dec	0.007	Zinc, mg/L (Max[b])	
beginning 2/1/95	report	through 1/31/95	0.88
Copper, mg/L (Avg[a])		beginning 2/1/95	report
through 1/31/95	0.03		
beginning 2/1/95	0.024		
Copper, mg/L (Max[b])			
through 1/31/95	0.06		
beginning 2/1/95	report		

[a] 30-day average
[b] Daily maximum
Source: ESA 1995.